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Bøtter-Jensen, L.; Christensen, P.; Leth-Nielsen, B.

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External Radiation Exposure Associated with Uranium/Thorium Mineralization on the Kvanefjeld Plateau, Greenland.

by

Lars Bøtter-Jensen, Poul Christensen and Bjarne Leth Nielsen +).

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Abstract

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The measuring programme included 1) environmental monitoring with TL dosimeters, high pressurized ionization chamber, and a plastic scintillometer, and 2) personnel monitoring with TLD badges of drillers and geologists during their survey programme.

A geological description of the area is given and results from the different methods of measurement are compared. The radiation exposure level data that were recorded make it possible to estimate the external personnel gamma radiation doses which may be obtained during future field work at Kvanefjeld. The annual personnel dose is calculated to amount to a maximum of 1.3 rad.

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INIS Descriptors

ARCTIC REGIONS
BACKGROUND RADIATION
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EXTERNAL RADIATION
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GREENLAND
IONIZATION CHAMBERS
LITHIUM COMPOUNDS
LITHIUM FLUORIDES
PERSONNEL MONITORING
PLASTIC SCINTILLATION DETECTOR
RADIATION DOSES
RADIATION MONITORING
THERMOLUMINESCENT DOSEMETERS
THERMOLUMINESCENT DOSIMETRY
THORIUM ORES
URANIUM ORES

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A radiation monitoring programme was carried out at Kvanefjeld, South Greenland, with the aim of estimating the level of external radiation exposure to personnel working in this area that has elevated background radiation levels because of extensive uranium and thorium mineralizations.

The measuring programme included 1) environmental monitoring with TL dosimeters, high pressurized chamber, and a plastic scintillometer, and 2) personnel monitoring with TLD badges of drillers and geologists during their survey programme.

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Introduction

Since 1956 the existence has been known of extensive uranium and thorium mineralizations at Kvanefjeld in South Greenland (1). These mineralizations have been geologically investigated on several occasions, but until 1977 no environmental radiation survey programme or personnel radiation monitoring had been carried out. Such studies were, however, initiated when intensified field work and core drillings started at Kvanefjeld in June 1977.

The Kvanefjeld area, which covers approximately 2 km^2, is a hilly plateau about 600 m above sea level (Fig. 2). It is situated 8 km to the north of the town of Narssaq at 60° 58' North and 46° 00' West. The area has a sub-arctic coastal climate with average temperatures in January and July of -3.3° and +7.5° C. In winter the major part of the precipitation takes the form of snow, but usually the plateau is almost free of snow from July to September. The vegetation is low and scattered, and the areal distribution of exposed rock, including blocks in situ, soil cover and vegetation is 50%, 25% and 25%, respectively. In this context the very high percentage of outcropping rocks is noteworthy because there are large coherent areas of radioactive rock on the surface of the plateau.

A health physics survey measuring programme took place during the summer (June, July and August) of 1977. This included environmental monitoring of important locations to represent the actual movements of people involved in future drilling activities, etc., and personnel monitoring of drillers and geologists during their survey programme.

This report deals with the problems related to radiation monitoring under arctic conditions, and results from different measuring methods are discussed and the basis for an estimation of the health physics consequences of future field activities at Kvanefjeld is given.

Geology and distribution of radioactivity

Kvanefjeld is situated in the north-western part of the Ilimaussaq alkaline intrusion (2). This intrusion, which is approx. 50 km^2 in size, is composed of an old series of syenites and granites and a younger series of under--saturated nepheline syenites. The radioactive occurrences are found within the so-called lujavrites, which are the youngest under-saturated differentiates of the intrusion. The lujavrites are rich in a number of rare elements, e.g. U, Th, Nb, Be, Zr, RE, Li. In the Kvanefjeld area the uranium content in the lujavrites varies from 100 to 3000 ppm and the average Th/U ratio is 2.6. Such concentrations of uranium may eventually be economically exploitable, and the drilling programmes in the southern part of Kvanefjeld before 1977 delineated 5800 tons U classified as reasonably assured resources, and 8700 tons U classified as estimated additional resources. The average grade of the ore is 300 ppm. The increase in ore tonnages originating from the last 5000 m drilling programme in 1977 is 21000 and 8000 tons U in the two classes, respectively. The uranium is contained in rocks with an average grade of 340 ppm U. These resources are located in the northern part of Kvanefjeld from the surface down to 200 m below the surface.

The geological map in Fig. 1, covering Kvanefjeld and a part of the Narssaq River Valley, shows the distribution of lujavrite and the older rock types. In general, Kvanefjeld makes up a large-scale intrusive breccia where the xenoliths of old rock are embedded in a lujavrite matrix.

The uranium and thorium in the lujavrite are contained in the minerals steenstrupine and monazite, as well as in pigmentary material. These minerals are disseminated in the lujavrite and the origin of the deposit is closely connected to the origin of the lujavrite. During the final crystallization, the uranium and thorium were concentrated in the last liquid in the magma chamber as well as in volatiles. An impermeable roof of lavas covering the intrusion prevented the escape of volatiles and in the very last phase of crystallization favoured the formation of minerals rich in rare elements including uranium and thorium. In addition to syngenetic enrichment of uranium and thorium in the lujavrite, some epigenetic enrichment with radio-elements has taken place, especially in altered lavas.

The deposit is exceptional not only in its mineralogical composition but also in its morphology. Most known uranium deposits display relatively limited radioactivity at the surface. At Kvanefjeld, however, the exposure of radioactive rock is very frequent and, being a disseminated type of ore, the source of radioactivity can in many places be regarded as infinite with respect to a detector.

As a number of the recorded doses refer to locations in Narssaq, the geological setting of this area is shortly described. The town is located on an extensive sheet of flat-lying gabbro. The gabbro, which is of low radioactivity, crops out at several places in the town, and generally the soils developed contain a high proportion of debris from the gabbro. Peat occurs in low-lying areas. The construction materials for roads, etc., are often of higher radioactivity consisting of alluvial materials from terraces in the Narssaq River Valley.

Environmental monitoring

Methods of measurement

The monitoring of environmental gamma exposure rates on the Kvanefjeld plateau was mainly concentrated in four areas of special geological character, varying from low-level to high-level radioactivity.

Besides these four areas, environmental radiation was monitored at a number of individual locations which, when taken together, represent the daily work and rest areas of the drillers and geologists and thus the range of radiation to which these staff were exposed.

The measurements were accomplished in three ways: 1) by thermoluminescence dosimeters (TLD), LiF TLD 700 (Harshaw), 2) by a high-pressurized ionization chamber, Environmental Monitoring System RS 111 (Reyter and Stokes), and 3) by an energy-compensated plastic scintillator system, Gammameter 2414 A (AB Atomenergi, Studsvik).

On each of the four main areas selected (see Fig. 1), nine locations were established with a mutual distance of 10 m and arranged in a square pattern of 3 x 3 to cover a representative, average part of the area. At each location a wooden post was errected on which to support a LiF TLD package 1 m above the ground (Fig. 2). The dosimeters remained in their field positions for approx. 3 months, and the integrated radiation exposures were determined using a thoroughly tested laboratory procedure. The positions of the post dosimeters were further used as fix points for the following additional survey measurements carried out with the ionization chamber and the plastic scintillator.

Instrumentation

The TL data were obtained with LiF, hot-pressed, solid TL dosimeters (3 x 3 x 0.8 mm) (Harshaw TLD 700). In addition to its excellent stability, LiF has a low Z number resulting in very little change in response per roentgen over a wide energy range (3).

The exposure rates 1 m above the ground were determined by Risø standard TLD units, each containing 3 LiF dosimeters. The TLD unit is a moulded plastic holder that contains the solid TL dosimeters as well as a binary hole code used for automatic processing. A sandwich shielding of 1 mm aluminium is provided to obtain electron equilibrium (4).

The dosimeters in the TLD units integrated the total exposure, including the cosmic and terrestrial radiation, while remaining at their respective locations. This enabled the evaluation of the mean exposure rates. On return to the laboratory, the dosimeters were read in an automatic TL reader (4), and each exposure was determined from the mean value of the three individual dosimeter responses.

Because the dosimeters were annealed and read at Risø, the dose received during transportation (transit dose) was determined in order to obtain the net value of interest. Therefore a reference point with low background radiation was selected near the monitoring site immediately after the arrival of staff and equipment in Greenland. The dosimeters were stored here during the intermediate periods together with the control dosimeters that accompanied the dosimeters during transportation and which were kept at the reference point during the whole period. Measurement of the exposure rate at the reference point by means of the ionization chamber, together with the response from the control dosimeters, allowed for the differentiation of the individually accumulated net exposure rates related to the different monitoring points, using the following equations:

$$X = \frac{R}{t} \text{ where}$$

$$R = R_{total} - (R_{ref.} + R_{transit})$$

$$R_{ref.} = X_{ref.} \times t_{ref.} \quad (X_{ref.} \text{ measured with ionization chamber})$$

$$R_{transit} = R_{control\ dos.} - X_{ref.} \times (t_{ref.} + t)$$

with X, R and t indication exposure rate, exposure and time, respectively, and control and ref. denoting control dosimeter and reference point, respectively.

The high-pressurized ionization chamber used for direct measurement of the exposure rates (5) was modified with a built-in tape deck for accumulating the data. Each monitoring point was measured over a period of approx. 10 minutes during which time the fluctuating exposure rate values were sampled each fifth second and transferred from a digital voltmeter (calibrated in uR/h) to the tape. On return to the laboratory, the sampled data were evaluated and the mean values calculated.

For intercomparison purposes, the exposure rates were likewise measured with a less complicated, portable, energy-compensated plastic scintillometer calibrated in μR/h, excluding a constant representing the cosmic ray contribution.

Calibration

A certified ^{226}Ra source (1 mCi) calibrated at Amersham was used for checking the instrument readings and for verification of the TL response.

The ^{226}Ra source was set up under optimal field conditions on a 3 m high wooden post where the geometrical influence of the scatter contribution as a function of distance and hight was calculated (6). The ionization chamber, the plastic scintillator and TL dosimeters were successively exposed on top of a further 3 m high wooden post placed at a distance of 3 m from the ^{226}Ra source. The calculated exposure rate in the detection position including the determination of the scatter contribution from the earth was intercompared with the instrument readings. Furthermore the ^{226}Ra TL response obtained here was compared with the TL response obtained with the ^{60}Co facility routinely used for TL calibrations and an overall common agreement was found within 1%.

Results

The exposure rates evaluated from the three monitoring methods applied are given in table 1, and Fig. 3 gives the ionization chamber and scintillator data plotted against the TL data.

The ionization chamber and TLD responses express the present individual total exposure and represent cosmic radiation including the sky-shine component in addition to terrestrial gamma radiation from fall-out and natural radio-nuclides as well as the scatter contribution due to field geometry.

The plastic scintillator, however, did not respond to the highly energetic cosmic radiation, consequently the data obtained with this instrument represent only the terrestrial component.

The reasonable agreement between TLD and ionization chamber data indicates an almost energy-independent response for the two detector systems.

The scintillator data show a typical average reduction of approx. 15% (excluding the cosmic contribution of approx. 4 μR/h) especially in non-idealized rocky field geometries where a higher intensity of a low energy scatter gamma component is present. This indicates that the plastic scintillometer has a poorer energy response, resulting in an underestimation of the exposure.

Locations 48-53 in table 1 refer to different places in Narssaq and it is notable that the exposure rate measured on the road (locality 53) is considerably higher than those measured elsewhere in the town area. This is because construction materials for roads in Narssaq consist of quaternary alluvial deposits derived partly from the Kvanefjeld area.

Personnel Monitoring

Methods of Measurement and Instrumentation

A personnel monitoring service was set up for the bore-drilling team, which comprised 16 persons all with well-controlled working area/time schedules. During non-working periods the badges were kept on a rack in the camp canteen, this area being considered representative of the background radiation of the camp locality. The exposure to the dosimeters during transport before and after the monitoring period was estimated from control dosimeters accompanying the badges during transport and remaining on the rack in the canteen during the whole monitoring period. The dose integrated while the dosimeters were in the canteen was evaluated from dose rate measurements made with the plastic scintillator. In addition to the dosimetry service set up for the bore-drilling personnel, a few other people doing work connected with the radiation survey at Kvanefjeld were supplied with personnel badges for the whole monitoring period.

The badges prepared for the measurements contained three types of TL-dosimeter: lithium fluoride (Harshaw, 25 mg TLD-700 chips), lithium borate (Risø, 25 mg tablets) and calsium sulphate (Harshaw, $CaSO_4$:Dy powder). The calcium sulphate was included to get information on the low photon-energy part of the measured exposures. To get an impression of the accuracy of the dose estimations under the extreme conditions prevailing during the drilling work, some of the dosimeters in the badge were given an exact dose before they were dispatched from Risø. To enable differention between depth dose and skin dose, a number of the dosimeters were covered with 1 mm aluminium. All dosimeters were worn in three-layered, welding-locked 0.2 mm polyethylene bags.

Results

The exposure data measured for the bore-drilling personnel are shown in table 2. The monitoring period was divided into two intervals,one representing the preliminary period when the camp was established and the other representing the actual bore-drilling. Exposures to the dosimeters during transport before and after the monitoring periods have been subtracted in the data shown in table 2. From work time-sheets prepared by personnel after each working period, the whole monitoring period was divided into periods of rest and of time spent working on the rock, respectively. Accordingly, from the measured exposure rate (75 uR/h) at the dosimeter rack in the canteen, a calculation could be made of the doses received during work and rest periods, respectively. This is shown in table 2. Table 3 gives the exposures measured for a group of people doing different categories of radiation surveying work on Kvanefjeld. The exposures during the rest periods were determined by integrating the measured background exposure rates (see table 1) over the rest periods. The data shown in both tables 2 and 3 demonstrate the importance of choice of camp location for the dose received during the whole period.

No significant difference was observed between the data obtained with lithium fluoride and with lithium borate; however, due to the higher fading of lithium borate, a better accuracy may be expected from the measurements based on lithium flouride. An impression of the accuracy of the estimated exposures was received from the evaluations of the pre-exposed dosimeters where the average estimate of a 200 mR pre-exposure to lithium fluoride was found to be 200.6 mR with a standard deviation of 8.7%, and the corresponding values for 1-R pre-exposures to lithium borate were 0.998 R and 6.4%, respectively. As expected, the exposures could on the whole be regarded as penetrating radiation. The average exposure ratio with/without a 1 mm aluminium shield was found to be 0.95 with a standard deviation of 4.5% and a minimum value of 0.88. The results of the calcium sulphate measurements showed an average ratio of the $CaSO_4$/LiF measurements of 1.28, indicating that only an insignificant part of the dose originated from photon energies below 100 KeV (7).

Conclusion

Kvanefjeld forms an area of elevated natural radioactivity. External gamma exposures to people during work and when residing in the area may be of the order of 10-50 times those in areas of "normal" background radiation.

The measured data may be used to estimate personnel doses in connection with future activities in the area. On this basis, the health physics consequences may be assessed.

Considering a ten-hour shift for 230 working days a year, the total annual personnel dose, according to table 1, area 4, can amount to approx. 1.3 rad as a maximum.

The data from the present personnel monitoring, however, show that an average annual personnel exposure of approx. 200 mR may be obtained (extrapolation of the data from table 2.). This seems to be in fair agreement with the field measurements considering the large variations in the exposure rate within the working area.

The present environmental and personnel monitoring programme relates to persons working and living in an area that has uranium and thorium mineralisations of large areal extent. The geometry of the radiation field is close to

2 π and the source is infinite with respect to a detector. The radioactive elements are finely, and on a large scale homogeneously disseminated in the radioactive rocks. During any kind of work on the surface, or in wide open-cast operations, these parameters should be applicable. Thus the radiation exposures measured in the area can be used in connection with future work at Kvanefjeld.

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Table 1

Results from environmental exposure rate measurements. The ionization chamber and plastic scintillometer data are measured directly, whereas the TLD data are calculated from integrated doses. Some of the ionization chamber data from area 4 are unreliable due to instrument saturation problems.

Area 1 — Medium-active, coarse-grained lujavrite area

Location	TLD μR/h	Ion-chamb. μR/h	Plast-scint. μR/h
1	199	194	180
2	246	240	230
3	214	214	200
4	264	248	220
5	275	269	240
6	208	211	195
7	260	263	240
8	222	226	210
9	404	398	370
Mean	255	251	232
SD	62.2	60.3	55.8
SD%	24.4	24.0	24.1

Area 2 — Low-active gabbro area

Location	TLD μR/h	Ion-chamb. μR/h
10	30.0	25.3
11	26.5	24.7
12	27.0	24.6
13	25.1	22.4
14	23.9	22.5
15	24.1	22.0
16	23.4	21.2
17	24.2	22.5
18	23.8	21.6
Mean	25.3	23.0
SD	2.2	1.5
SD%	8.7	6.5

Area 3 — Medium-active, homogeneous luvjabrite area

Location	TLD μR/h	Ion-chamb. μR/h
19	270	257
20	298	275
21	279	264
22	250	245
23	271	254
24	298	281
25	196	185
26	203	189
27	212	207
Mean	253	240
SD	40.0	36.6
SD%	15.8	15.3

Area 4 — High-active, heterogeneous luvjavrite area

Location	TLD μR/h	Ion-chamb. μR/h	Plast-scint. μR/h
28	583	571 x)	550
29	698	580 x)	620
30	586	533 x)	500
31	641	579 x)	560
32	638	579 x)	540
33	583	559 x)	520
34	489	472	420
35	531	514	460
36	426	413	380
Mean	575		506
SD	83.1		74.7
SD%	14.5		14.8

Additionally monitored locations

Location +)	TLD μR/h	Ion-chamb. μR/h	Plast scint. μR/h
37	264	262	255
38	344	355	320
39	39.8	40.3	
40	54.7	52.0	
41	51.2	45.9	
42	412		350
43	874		750
44	1281		1150
45	1309		1150
46	1461		1100
47	239	234	200
48	9.41		
49	9.29		
50	12.26		
51	8.7	8.8	
52	8.8	8.8	
53		16.4	14.0

x) Saturation of ionization chamber.

+)
37. Geologists' house on Kvanefjeld, bedroom
38. Geologists' house on Kvanefjeld, bedroom
39. Geologists' camp in Valley, bedroom
40. Geologists' camp in Valley, barn (crusher)
41. Geologists' camp in Valley, outside the canteen
42. Mine area
43. Mine area
44. Mine area
45. Mine area
46. Inside the mine gallery
47. One location on Kvanefjeld
48. Inside a house in Narssaq
49. Inside a house in Narssaq
50 Outside the hotel in Narssaq
51 + 52. Low-activity reference point in Narssaq
53. Square in front of the KGH shop in Narssaq

Table 2.

Bore-drilling personnel exposures. Data are given separately for two periods: The initial period of 21 days used for establishing the residence camp, and the bore-drilling period amounting to 79 days. The bore-drilling period is divided into exposures obtained during rest and work, respectively.

Person no.	Exposure, mR			Total
	Initial period (rest and work)	Bore-drilling period		
		Work-period	Rest period	
1	24	33	117	174
2	23	40	109	172
3	23	32	103	158
4	27	38	100	165
5	24	32	109	165
6	23	38	105	166
7	24	40	109	173
8	23	77	85	185
9	23	13	126	162
10	23	58	107	188
11	24	-	144	168
12	23	-	134	157
13	23	-	141	164
14	23	Lost	Lost	-
15	23	79	91	193
16	23	75	95	193
17	23	39	97	159

Table 3.

Radiation-survey personnel exposures. The exposures measured during the total monitoring period are divided into exposures received while in the accommodation area and while at work on the Kvanefjeld plateau, respectively.

Person no.	Total monitoring period (days)	Accommodation area	Exposure, mR		
			During total period	While in accommodation area	While at work
1	12	Geologists' camp in Valley	13	11	2
2	7	Geologists' camp in Valley	11	8	3
3	16 41	Geologists' camp in Valley House on Kvanefjeld	330	20 290	20
4	11	Hotel "Narssaq"	6	1	5

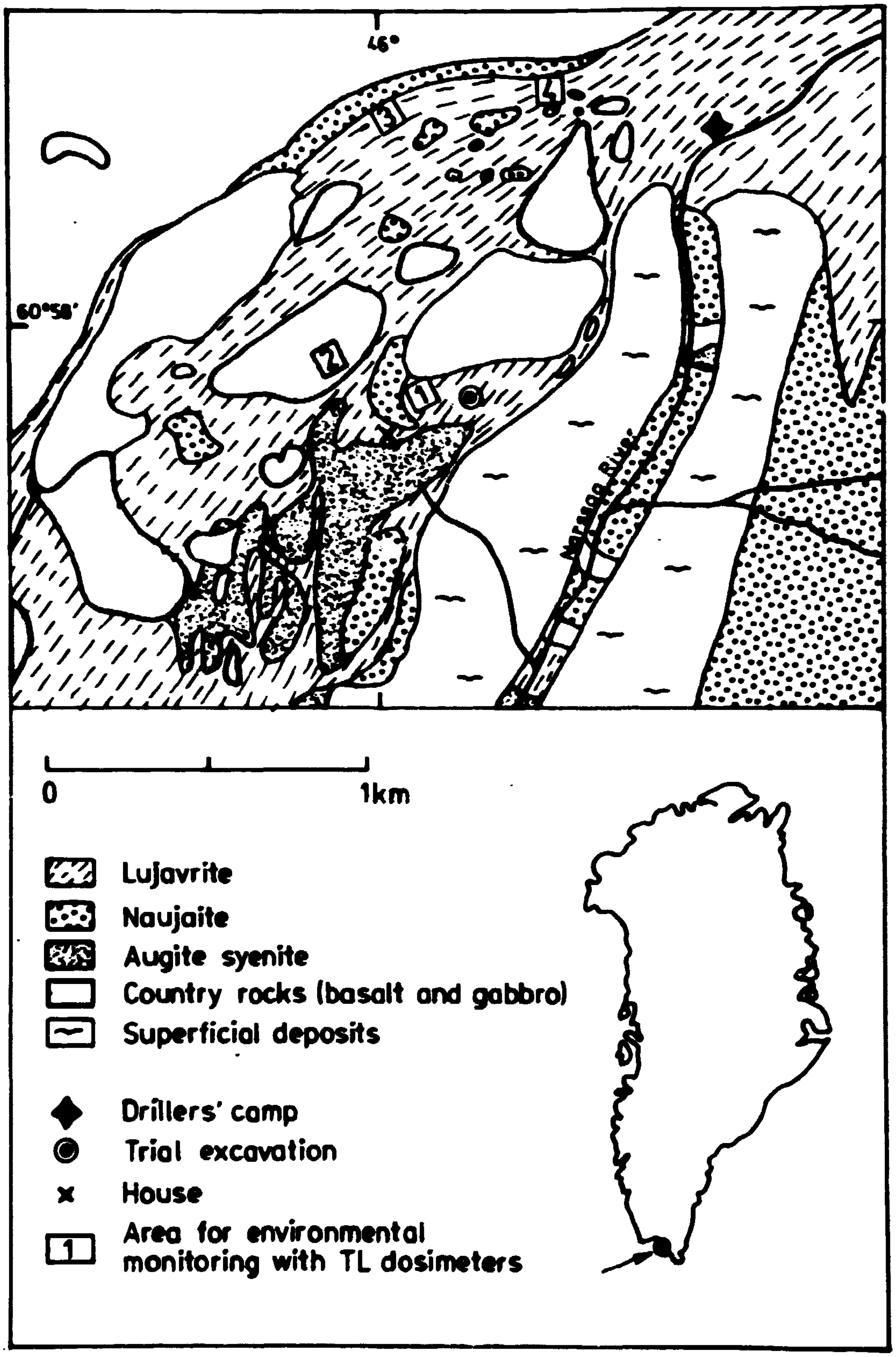

Fig. 1. Simplified geological map of the Kvanefjeld area.

Fig. 2. View of the Kvanefjeld plateau with a TL dosimeter post in front to the right and the high-pressurized ionization chamber positioned behind to the left.

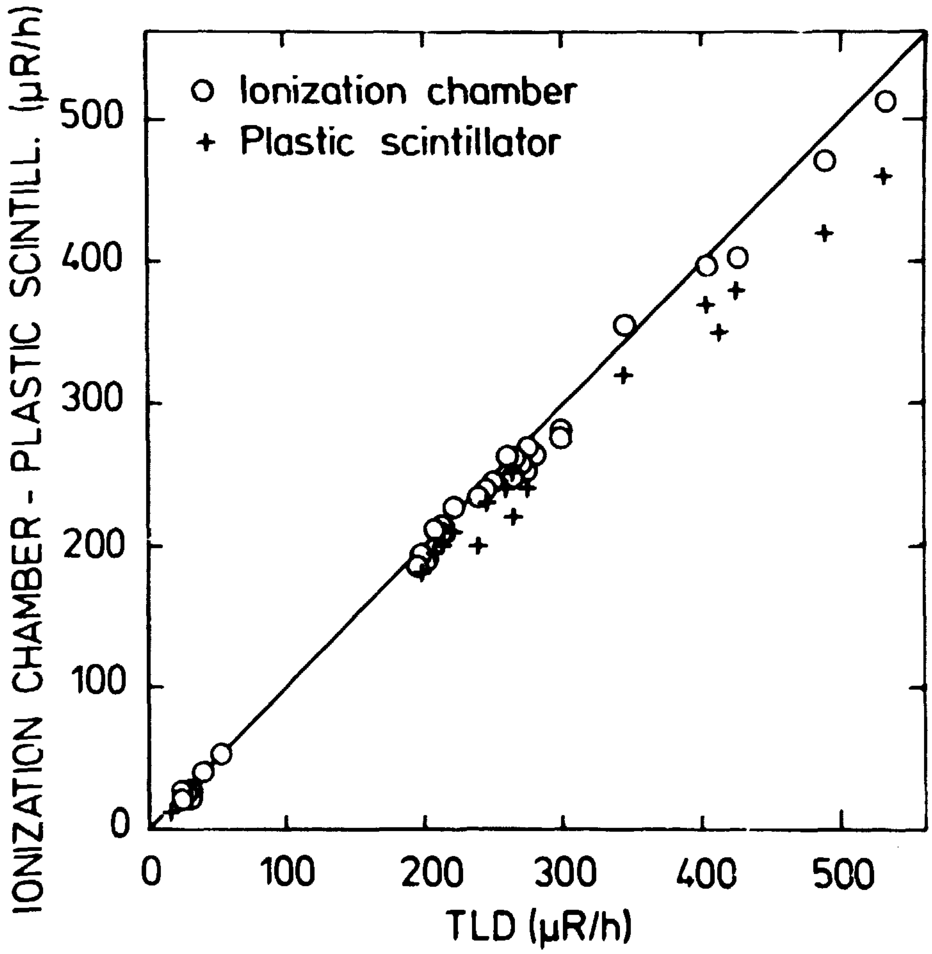

Fig. 3. Ionization chamber and plastic scintillometer data plotted against the TLD data.